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Analysis of the T63-A-700 Engine used in Alcohol Turbine Fuel Extender Test

John S. Glaeser
Depot Engineering and RCM Support Office
U.S. Army Aviation Systems Command
Naval Air Station, Corpus Christi, Texas

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16. Abstract

The teardown analysis of the T63-A-700 engine used in fuel extender research at the Federal Aviation Administration (FAA) Technical Center was conducted by the United States Army Aviation Systems Command (AVSCOM) Depot Engineering and Reliability Centered Maintenance Support Office (DERSO) in order to assist the FAA in completing an evaluation of the use of alcohols as extenders for the existing turbine fuels.

The turbine section of the T63-A-700 engine displayed burned vanes on the first stage gas producer. In addition, the blade tips of the second stage gas producer turbine rotor had rubbed the interior of the second stage gas producer nozzle. It was concluded that the vanes on the first stage gas producer burned during a series of hot or hung starts using extender fuels. The inefficiency of both the fuel nozzle and the fuel control unit using alcohol blends during starting operations caused the overtemperatures. The second stage gas producer nozzle was warped as a result of thermal cycling from ambient temperature to a hot or hung start condition that caused the turbine rotor tips to rub the nozzle. The remainder of the engine, including the seals, fuel control unit, fuel nozzle, bearings, and internal components, showed no discrepancies. Much of the change appears to have resulted from hung starts. Future evaluations of extender fuels should consider using design fuels during starting operations and then introducing extender fuels after the engine has reached normal operating conditions.

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EXECUTIVE SUMMARY

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INTRODUCTION

The Federal Aviation Adminstration (FAA) Technical Center evaluated the performance of alcohol as extenders for rhe existing aviation turbine fuels. The evaluation, which was conducted at the FAA Technical Center dynamometer facility, used a T63-A-700 engine. The engine used in this project was loaned to the FAA by the United States Army Aviation Systems Command (AVSCOM).

Various experimental fuel blends were evaluated in the T63-A-700 static test cell tests. These blends consisted of either ethanol or methanol mixed with either JP-4 or Jet-A, and the alcohol concentration varied from 5 to 20 percent. The engine accrued approximately 120 total hours during the evaluation.

It was decided that a teardown analysis of the engine would not be performed at the FAA facility in Atlantic City, NJ. The engine was shipped to the Corpus Christi Army Depot (CCAD) after completion of the evaluation.

The AVSCOM Depot Engineering and Reliability Centered Maintenance Support Office (DERSO) assisted the FAA in the final evaluation. DERSO is collocated with the CCAD complex at the Naval Air Station, Corpus Christi, TX. DERSO assigned a project engineer to conduct the teardown analysis of the engine.

A four-point project plan to complete the engine teardown analysis was developed. It included a visual inspection, a test cell run to determine the operating characteristics, a complete teardown inspection to determine failure modes of internal components, and an analysis of all internal engine and fuel control unit seals for deterioration. Emphasis was placed on the engine hot (turbine) section and the fuel system. Funds for this project were limited and allowed no additional analysis.

VISUAL INSPECTION

The T63-A-700 engine, serial number AE403067BCD, was inspected at the CCAD Engine Pre-shop Analysis Section to insure that the engine was test-cell ready. The hot section of the engine displayed a carbon/exhaust buildup on the exterior of the engine case. This buildup is suspected to be from hot or hung starts resulting from use of the alternate fuel mixtures.

The fuel system had been modified to include a T-fitting in the fuel line prior to the fuel control unit. This modification was used for fuel pressure measurements. The engine turbine section rotated freely by hand and exhibited no binding or rubbing. Therefore, the engine was transferred to the test cell for an operational test.

TEST CELL

The fuel used during this test run was MIL-J-5624, JP-4.

The engine was placed in test cell number 9. Pre-test troubleshooting revealed that the ignition exciter was inoperable. A serviceable exciter was installed, and the engine started normally.

The engine oil consumption during the test cell run was normal.

The specific fuel consumption for the engine was consistently higher than the maximum allowable (figure 1).

Extrapolation of the test cell data indicates that the engine will produce rated power at 105 percent N1 speed, 1484 ^{O}F turbine outlet temperature, and 93.5 foot-pound-force (ft·lbf) torque, when corrected to standard day, sea level conditions. Obviously, the engine was not run in the test cell at these conditions as the maximum operating temperature was 1380 ^{O}F (table 1).

The engine was operated through all ranges of power settings. Table 2 reflects the test run parameters. At all power settings, the shaft horsepower (referred to standard day, sea level conditions) was lower than the minimum specified in TM55-2840-231-23, Aviation Unit and Intermediate Maintenance Manual, Engine Assembly (figure 2).

TEARDOWN

After the functional test, the engine was transferred to the CCAD Engine Pre-Shop Analysis Section area for teardown analysis. The fuel control unit and the fuel nozzle were transferred to the CCAD Fuel Control Shop for analysis.

The engine disassembly revealed several discrepancies in the hot section. The first stage gas producer nozzle vanes had burned trailing edges. One 3-vane section of the nozzle was burned more heavily than the remainder of the vanes (figure 3).

The second stage gas producer turbine rotor blade tips had rubbed the top and bottom of the second stage gas producer nozzle cylinder. Dimensional checks were conducted on the gas producer nozzle. The only discrepancy was the flatness of the forward flange face which is adjacent to the cylinder. When the faces were measured on a flat measuring table, one face of the nozzle flange was found to be 0.006 inch high. This is an indication of nozzle warpage. The high point was located 90 degrees from the rubbed areas of the cylinder.

The number eight bearing had some discoloration, which indicated some slight overheating in the gas producer section of the turbine assembly.

The fuel control components were all in working order. The fuel control seals had no evidence of deterioration. The fuel nozzle was clean and showed no discrepancies which would have altered the fuel atomizing pattern.

The remainder of the engine components displayed no defects.

ENGINEERING ANALYSIS

First stage gas producer nozzle - The nozzle was analyzed at the CCAD Metallurgical Laboratory. An examination of the burned cross-section confirmed incipient melting in this area of the nozzle (figure 4). The number of engine hours at the time the nozzle started to burn is unknown. The type of fuel in use and the engine operating parameters when this failure commenced is also unknown; however, the following hypothesis is probable. The inspection of the fuel nozzle and the fuel control unit installed in this engine revealed that they were operating normally. The fuel atomization pattern for this nozzle was proper for normal operating conditions. However, the alcohol fuel mixtures may have altered the flame pattern during starting and low power requirements, particularly during hot and/or hung starts. In addition, the flame speed when operating on alcohol fuels is slower, and it is possible the flame front extended beyond the burner can. This further compounds the overtemperature problem during a hot or a hung start.

Second stage gas producer nozzle - The dimensional check of the nozzle indicated warpage at a point 90 degrees from the rotor tip rub marks. The rub marks were 180 degrees apart and were uneven in length and depth. This would confirm warpage at only one point on the nozzle as measured in the laboratory. The cause for the nozzle warpage was most likely due to higher than normal starting temperatures from the alcohol blends and was aggravated by the burned nozzle vanes during starting. Thermal cycling from ambient temperatures to a start or hot start condition may have contributed to the warping. A portion of the vanes also burned away. Heat transfer between the vanes and the perimeter of the nozzle increased allowing a more rapid thermal cycle to the unit.

Second stage gas producer turbine rotor - The blade tips of the rotor had rubbed the second stage nozzle due to the warpage and elliptical shape of the nozzle itself. The rotor blade tips were worn due to the rubbing. This rubbing effect may have resulted in hung starts until the blades tips had worn and the nozzle gouge was deep enough to allow freewheeling of the turbine in the nozzle.

CONCLUSIONS

The behavior of the engine in the test cell run (low shaft horsepower and high specific fuel consumption) was confirmed during teardown and analysis and revealed the inefficiency of the burned first stage gas producer nozzle vanes.

It is probable that the ethanol and methanol blends with jet fuel influenced the efficiency of both the fuel control unit and the fuel nozzle, particularly during engine starting operations.

It is unknown how or when the first stage gas producer nozzle was exposed to temperatures high enough to burn the nozzle vanes. The engine analysis indicates that some combination of blended fuels and a hot or hung start precipitated the problem.

It is also unknown what effect the damaged hot section had on the results of the evaluation itself. It is possible that consistent reproducibility of the evaluation results were affected after the hot section of the engine became damaged.

Assuming that the alcohol blends contributed to the hot section damage during starting operations, it follows that consideration should be given to using only jet fuel to start gas turbine engines. Extender fuels would be introduced after the engine reached normal operating conditions. This would require additional testing to confirm the above assumption. The Federal Aviation Administration Technical Center reported that the incidence of hung starts was reduced by starting the test engine on either neat Jet-A or neat JP-4.

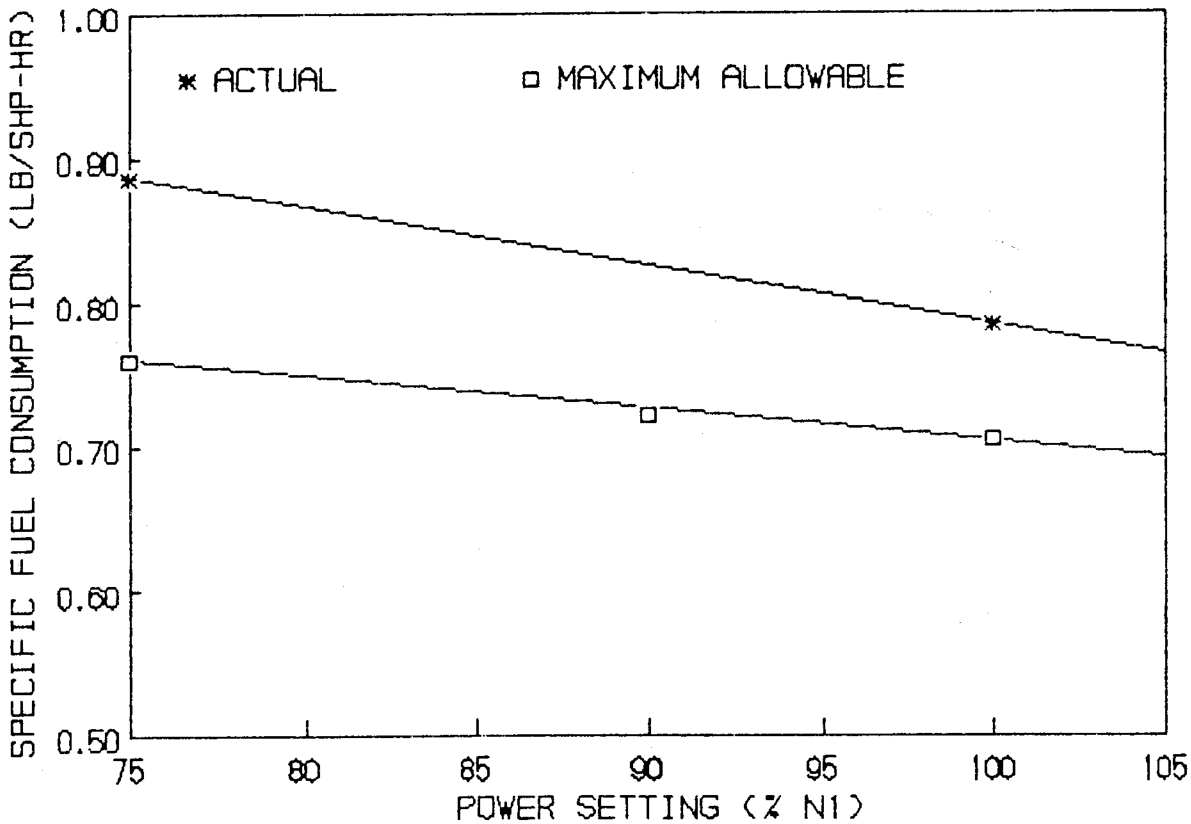

FIGURE 1. FUEL CONSUMPTION COMPARISON

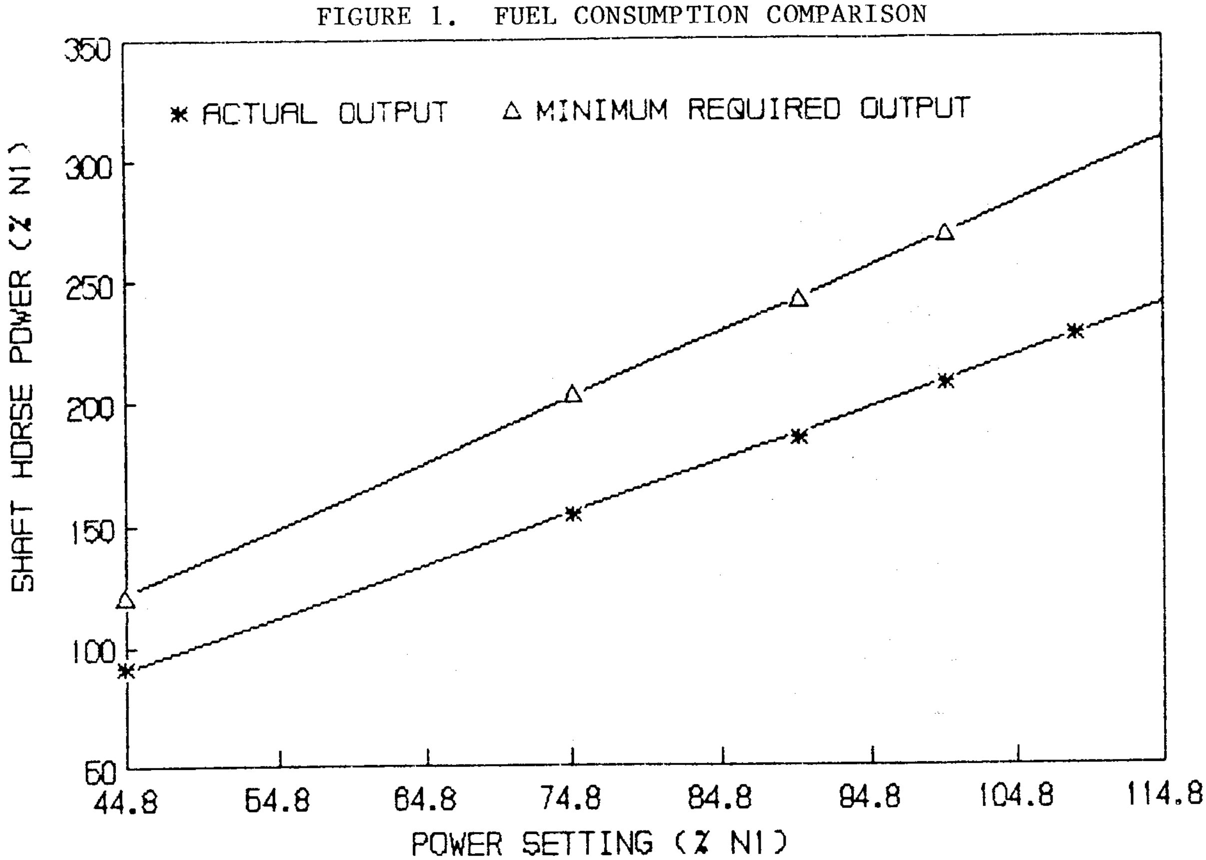

FIGURE 2. OUTPUT POWER COMPARISON

FIGURE 3. THE AFFECTED TRAILING EDGES

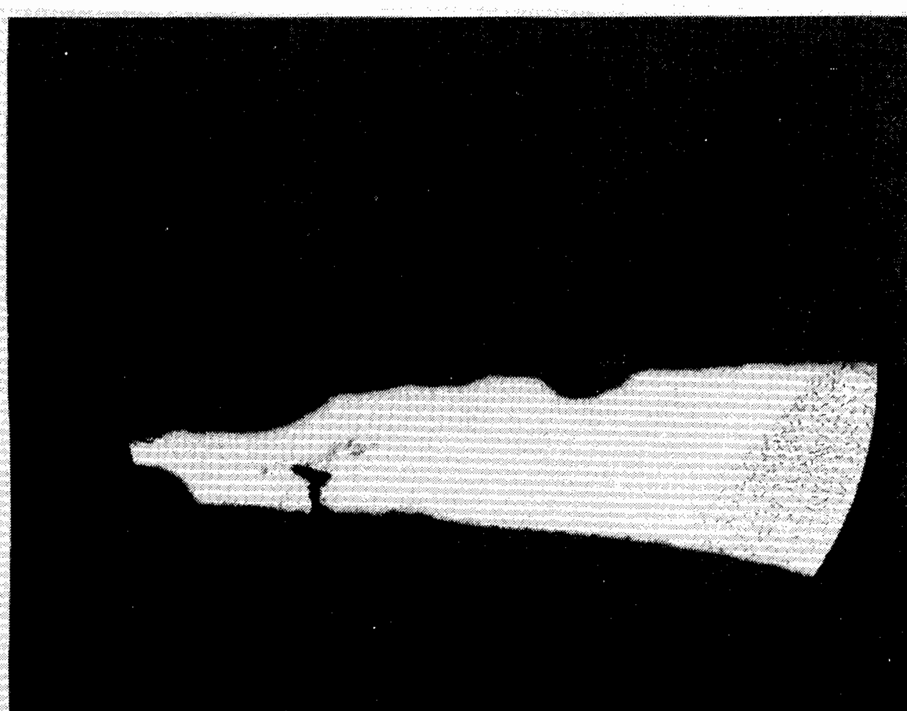

FIGURE 4. TRAILING EDGE SHOWING INCIPIENT MELTING

TABLE 1. PERFORMANCE RATINGS (STANDARD SEA LEVEL STATIC CONDITIONS)

Rating	Shaft HP (min)	Net jet thrust lb (min)	Gas producer speed rpm (%) (est)	Output shaft rpm	Specific fuel consumption lb/SHP-hr (max)	Ram power rating torque at output shaft ft-lb (max)	Measured rated gas temp °F (°C) (max)
Takeoff	317	33	51600 (100.9)	6000	0.697	293	1380 (749)
Normal	270	28	49760 (97.3)	6000	0.706	249	1280 (693)
90% normal	243	26	48650 (95.2)	6000	0.725	249	1226 (663)
75% normal	203	21	46950 (91.8)	6000	0.762	249	1148 (620)
Start and idle	35 max	10 max	32000 (62.6)	4500-6300	61 lb/hr	—	750 ± 100 (399 ± 56)
Flight autoration	0 max	10 max	32000 (62.6)	5900-6480	61 lb/hr	—	725 ± 100 (385 ± 56)

NOTE: Specific fuel consumption = fuel flow/SHP.

TABLE 2. GAS TURBINE ENGINE TEST LOG SHEET

RIN:T02RJ300247 PRINTED 11/01/90/07:53:57 PAGE 1 OF 2

TEST ACTIVITY								STARTING	COMPLETING
CORPUS CHRISTI ARMY DEPOT		SER.NO.AE403067BCD		STAND NO.09	PRE-OIL	90010	OPERATORS	CHUPE,U.	MUNSON,P.F.
CORPUS CHRISTI,TEXAS		SEQ.NO.090Y.0021		TEST NO. 1	IN-PROCESS	90010		HOWARD,B.J.	MARTINEZ,G.,JR.
TYPE TEST- MINOR		TYPE/MOD T63-A700		RUN TIME 4:34			INSPECTOR NUMBER		

POWER SETTING	GI	44.8	61.5	75.0	90.0	100.0	108.9	T/O
RUN MODE	A	A	A	A	A	A	A	A
TIME OF DAY	0933	1629	1635	1640	1644	1647	1650	1654
ELAPSED TIME	:08	:16	:06	:05	:04	:06	:03	:38
N1 SPEED	62.6	85.1	88.4	91.9	94.9	97.3	99.0	101.1
N1 SPEED REF		84.4	87.7	91.1	94.2	96.6	98.2	100.3
N2 SPEED	79.7	100.0	100.0	100.2	100.0	100.2	100.0	100.1
LOAD	120	970	1300	1630	1950	2210	2430	2690
SHP MAXIMUM		106	151	197	243	277	312	336
SHP ACTUAL	9	93	124	156	186	211	232	257
SHP REFERRED		92	122	154	183	208	229	253
MGT ACTUAL	828	999	1073	1147	1228	1279	1327	1378
MGT REFERRED		974	1050	1119	1202	1252	1296	1350
COMP IN TEMP	63	68	67	68	67	67	68	67
OIL IN TEMP	217	211	211	200	198	197	196	196
OIL OUT TEMP	224	228	249	235	234	237	239	241
FUEL IN TEMP	68	63	63	63	63	63	63	64
TORQUEMETER	4.3	28.2	36.8	45.7	55.2	62.3	68.5	75.9
GEARBOX PRESS	.5	2.8	3.7	3.7	3.7	3.9	3.5	4.1
OIL IN PRESS	.0	.6	.7	.6	.7	.6	.6	.6
OIL SCAV PRESS	25.9	32.1	31.7	32.5	33.1	33.0	33.3	33.5
OIL PUMP PRESS	71.5	122.4	123.4	127.6	127.7	127.6	127.4	127.1
FUEL IN PRESS	32	29	28	28	28	28	28	28
BAROMETER	30.51	30.22	30.23	30.23	30.23	30.23	30.23	30.22
BLEED EXH TEMP	107	80	101	89	82	84	83	81
BLEED REF TEMP	67	74	82	72	72	72	73	72
COMP SEAL VENT PR	5.01	5.37	5.63	5.75	5.63	5.19	3.98	4.23
ANTI-ICE AIR TEMP	80	156	83	158	81	79	81	78
FUEL FILTER DIFF	.00	.07	.07	.07	.06	.06	.06	.05
FUEL FLOW	56	102	119	136	153	169	179	192
FUEL FLOW REF		102	119	135	152	168	178	191
VIBRATION #1	.40	.20	.20	.20	.20	.20	.20	.20
VIBRATION #2	.10	.20	.20	.20	.20	.20	.20	.20
VIBRATION #3	.10	.10	.10	.10	.10	.10	.10	.20
VIBRATION #4	.40	.00	.20	.20	.30	.30	.20	.20

THIS ENGINE WILL PRODUCE RATED POWER AT 105.8%N1 SPEED,1484F/807C MGT,AND 93.5 PSI TORQUE AT STANDARD DAY SEA LEVEL COND.

TABLE 2. GAS TURBINE ENGINE TEST LOG SHEET (Continued)

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RIN T02RJ300242                                                         PRINTED 11/01/90/07:56:02 PAGE 2 OF 2

SER.NO.AE403067BCD        SEQ.NO.090Y.0021 REC.NO. 1 O/G S/N SAM        F/C S/N CASS        OIL MIL-L-23699 FUEL MIL-J-5624 JP-4
CRV.SET *       6  LIM.SET *        6 LIM.MOD * M  CP1X      .00   CP2X      .00  PT1X      .00  PT2X      .00     SPEC. GRAV. @ 60F .742

S/S    START  STOP  START  STOP  START  STOP
   MGT 1034         1108         1048
   ET  15.9   40.9  12.5   40.0  11.3   43.9
   TOD 0741   0906  0920   1101  1611   1701

OS GOV CHECKS  %N1    %N2   LOAD   SHP   MGT   TOD  ET
   DROOP CK    73.2  107.5    70     7   844   0847 :11
   DECAY CK    87.0  105.7  1000   101  1013

ACCEL CHECKS  %N1   SECS  MGT                  TOD  ET
   FI TO     106.7   1.8 1250                  1033 :02
   FI TO     106.7   1.7 1265
   T/O TO  GI        3.0  923
   T/O TO  GI        2.8  987

POWER SETTING          75%        NORM.     T.O.
MGT                   1148        1280      1380
SHAFT HORSE POWER      158         231       268
% VARIANCE          22.167      18.148    15.457
S.F.C.(WF/SHP)        .880        .787      .746
% VARIANCE          15.486      10.534     7.030

SHP   122      230
SFC  .967     .778

SEAL RUN-IN TIME        :09
OIL CONSUMPTION    .000 PPH
COMPR SEAL VENT ORIFICE   02
ANTI-ICE TUBES TEMP RISE  177
LHV    18676
```

TABLE 3. LEADING PARTICULARS

Dimensions	
Length	40.4 inches (1.03 m)
Height	22.5 inches (0.57 m)
Width	19.0 inches (0.48 m)
Engine weight (dry):	
T63-A-700	138.5 pounds (62.82 kgr.)
Maximum oil consumption	0.05 gal/hr (6.5 oz/hr)
Lubricating oil specifications	MIL-L-23699 or MIL-L-7808
Fuel specifications:	
Primary	MIL-T-5624 (JP-4)
Alternate	MIL-T-5624 (JP-5) (JP-8) (JET-A) (JETA-1)
Emergency	MIL-G-5572
Design power output	317 shp
Ram power rating	335 shp
Design speeds:	
Gas producer (N1)	100% (51,120 rpm)
Power turbine (N2)	100% (35,000 rpm)
Power output shaft	100% (6,000 rpm)

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